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MEASUREMENT OF THE INTERNAL FORCES OF SEEDS.

By Charles A. Shull.

IT IS a well-known fact that when dry organic matter of any kind, as dry seeds, is brought into contact with water it imbibes moisture with great rapidity and swells with considerable energy. The water enters the swelling body in response to powerful internal forces which owe their existence and also their magnitude to the fact that the organic matter is composed of extremely minute particles which exhibit surface force. These forces, sometimes referred to as imbibition force, capillarity, surface force, etc., will be designated here simply as internal forces, since we have to deal with the resultant of a number of forces as expressed in the attraction of seed substance for water.

Furthermore, the universal presence of hygroscopic moisture in such organic matter is well known, and the fact that this moisture varies in quantity from day to day is a common observation. At all times the amount of water present in an air-dry seed, for instance, is determined by the balance between external forces which tend to remove water from the seed, and internal forces which resist this removal and which immediately cause moisture intake whenever they happen to exceed the external forces. In other words, moisture flows into or out of the seed as one set of forces or the other is the greater.

It must be noted, also, that the relation of these forces to water itself is such that as the water flows back and forth in response to given physical conditions, the greater force is always lessened by the movement of water, while the lesser force is simultaneously increased by that same movement of water, for instance, when the evaporating power of air is higher than the internal water-holding forces of the seed, the seed dries out. The moisture leaving the seed decreases the evaporating power of the air by increasing its vapor pressure, while the internal forces of the seed increase with surprising rapidity as the seed dries out, due to the thinning of the internal surface films. Again, if the surface force of a soil were greater than the internal force of the seeds, moisture would pass from the seed to the soil, increasing the thickness of the surface films of the soil particles and thereby decreasing their surface attraction for water, while the internal forces of the seed increase as in the previous case. Finally, where the seed possesses a semipermeable coat, and lies in an osmotic solution whose pressure is greater than the internal forces of the seed, water is extracted from the seed, which dilutes the osmotic solution and lowers its force, while, as before, the internal force of the seed increases rapidly as it loses water. In each case the movement of water continues only until the two forces, unequal at the start, become equal. This establishes moisture equilibrium, and further movement of water must be consequent to some disturbance, either external or internal, of the balanced condition of the forces. It is because of this relationship of the forces to water itself that the seed under natural conditions never becomes absolutely dry. For as it approaches dryness, the internal forces of the seed far exceed the evaporating power of the driest natural atmosphere.

Few attempts have been made to measure the magnitude of the internal forces of the hydrogels that make up the seed. The measurement of forces which cause the entry of water into *absolutely dry* organic matter has been attempted, the values being calculated from the amount of heat released during imbibition. Such release of heat energy during imbibition was probably first observed by Pouillet. As early as 1865 Jungk suggested that the liberation of heat by finely divided bodies, on being wet, was due to a compression or condensation of the fluid by the surface force of the fine particles. Oven-dried starch, for instance, on being wet with water of the same temperature, often shows a rise of 10 to 12 degrees. It is estimated that a rise of .03° C. requires about 34 atmospheres of pressure, so that a rise of 11 degrees indicates a surface force far exceeding 10,000 atmospheres on the particles of absolutely dry starch.

Lagergren, in 1898, found that a gram of powdered charcoal having 4 meters of internal surface required about .224 g. of water to wet it, and that a little over 8 calories of heat was liberated by the wetting process. If a whole gram of water were to be used with as large a mass of charcoal as it could wet, the heat liberated from that one gram of water would be about 36 calories. Basing his calculation on the known quantity of heat liberated by water on condensation by pressure, he estimates that this heat production would require at least 6150 atmospheres of pressure. Similar surface forces have been suggested for soils. Thus Mitscherlich, by using an ice calorimeter, has measured the heat of wetting in soils, and finds that the quantity of heat liberated varies with the physical character of the soil, the finer soils yielding larger amounts of free energy. Brown and Smith explain the fact that bacteria can continue the nitrification process in frozen soils by suggesting that these surface forces in soils may prevent the freezing of the water nearest the soil particle. They state that the force of surface condensation has been estimated at from 6000 to 25,000 atmospheres.

However, forces of such magnitude as these do not occur in ordinary air-dry seeds, for they already contain as hygroscopic moisture the water which would be taken up with such tremendous force if they were absolutely dry. But they do give us a clear idea of the power with which the seed retains the last part of its hygroscopic moisture, for this must be a force opposite and equal to that with which wetting occurs.

The discovery of perfectly semipermeable seed coats in barley by Brown in 1907, in wheat by Schröder in 1909, and in *Xanthium* by myself in 1912, laid open the way to measuring the ordinary internal forces of seeds by osmotic solutions. Such measurements were made by the writer a couple of years ago for the seeds of several species of *Xanthium,* using saturated lithium and sodium chloride solution, and more dilute solutions of the latter salt to provide the external forces. Seeds were placed in solutions of various concentrations, and allowed to come to moisture equilibrium, which was indicated by constancy in the weight of the seeds. The osmotic pressure, calculated by physical chemical methods, gave the external force, and therefore the equal internal force of the seeds when they had come to equilibrium with that strength of solution.

While the forces were by no means so large as those indicated for oven-dried matter, still they were found to be of considerable magnitude. In saturated solutions of sodium chloride the seeds were able to crystallize the salt out of solution by withdrawal of pure water from its hydration compounds. It was found that an air-dry seed of the cocklebur, when its hygroscopic equilibrum was represented by 7 per cent of moisture, had an initial internal pressure of but little less than a thousand atmospheres (965), or more than 14,000 pounds per square inch. When the moisture content of the seed has been increased until it amounts to about 14 per cent of the absolute dry weight of the seed (about 7 per cent beyond the ordinary hygroscopic moisture) the internal force is a little less than 400 atmospheres at ordinary temperatures. And so the internal force could be determined for any particular moisture content.

The assumption is made that moisture equilibrium results from the interplay of forces which actually become equal when equilibrium is attained. In other words, I am assuming that the total osmotic pressure is transmitted as force when pitted against the internal force of the seed. While definite proof as to the validity of this assumption can not be offered at present, there is some supporting evidence, and unless or until it is shown to be erroneous it is believed to be justified.

Obviously, this method of measurement can be applied only to seeds which have perfectly semipermeable coats. But many seeds have permeable testas, or possess an open micropyle, which makes the application of such a method impossible. A new method of measuring the internal forces of seeds is now being perfected which can be applied to any seed regardless of the character of the coat. It is based on the assumption that osmotic pressure can be computed from vapor pressure—an assumption whose validity is admitted by practically all physicists and physical chemists—and that the vapor pressure of the seed hydrogels measured against the vapor pressure of strong solutions is a true measure of the internal force of the seed. Although not proven valid, this second assumption seems as reasonable as the first; and in actual practice the values obtained for the internal forces of the seed colloids by this method are fairly concordant with those obtained by the osmotic-pressure method.

This method consists of suspending the air-dry seeds in an enclosed atmosphere over a series of sulphuric acids of varying strengths from very dilute to the pure acid as obtained from the stock bottles, *i. e.*, acid of about 1.83 specific gravity. Over the dilute acids, where the vapor pressure is relatively high, the seeds imbibe moisture because their own vapor pressure is lower. This imbibition continues until the vapor pressure of the seeds and that of the solution over which they lie are equal. This establishes equilibruim of forces, and no further change occurs. The higher the vapor pressure of the solution, the larger the amount of adjustment which occurs; and the lower the vapor pressure, the smaller the adjustment necessary for attainment of equilibrium relations.

Above the concentrated acids, where the vapor pressure of the solutions is low, the seeds lose moisture because their own vapor pressure is higher. They continue to lose moisture until the vapor pressure of the seeds is reduced to that of the solution below them, after which no change occurs, as the equilibrium is established at that point. The loss is greatest over the strongest acid, and is successively less as the vapor pressure increases by dilution.

Between these two extremes there is a point which is easily established where the seeds neither gain nor lose in moisture because the vapor pressure of the seed colloids and that of the solution are equal at the start.

Using the original weight of the seeds as a base line, and calling percentage of gain in weight positive, and percentage of loss in weight negative, a curve can be constructed, connecting the equilibrium points in the series. This curve cuts the base line at the point of natural equilibrium. In order to determine the original internal force of the seeds, all that is necessary now is to determine the osmotic pressure of the sulphuric acid over which seeds neither gained nor lost in weight.

This is done from the data by using the vapor-pressure formula for determining osmotic pressure given in all the physical chemistries, and securing the necessary values from the physical chemical tables of Landolt-Börnstein. In one such determination the internal force of an air-dry seed was found to be more than 900 atmospheres, which is not in serious disagreement with the values found by the osmotic-pressure method. A difference of one per cent in the hygroscopic moisture of the seeds with which the two tests mentioned were carried out would make much more than 100 atmospheres of difference in the internal force of the seed. Since the difference between the two tests is only about 50 atmospheres, a fraction of one per cent difference in the original moisture content of the lots of seeds would account for the entire difference. The closeness of the agreement speaks strongly for the accuracy of the methods and for the validity of all assumptions involved in the mode of procedure.

The high values found for the internal forces of the seed are significant in connection with the physiology of the seeds of agricultural plants. It has been observed, as, for instance, in Bulletin No. 23, Bureau of Soils, that seeds can secure much moisture from soils which contain only a small amount of water. A loam soil holding 15 per cent of moisture yielded it to air-dry beans so freely that at the end of twelve hours the beans had taken up 60 per cent of their weight of water. A very striking experiment consisted in mixing 50 grams of air-dry cowpeas, whose hygroscopic moisture was about 14 per cent, with 50 grams of soil which contained 15 per cent of water. In twelve hours the cowpeas took up 12.1 per cent of their weight of water, leaving only 1.3 per cent in the soil. That is, the soil was nearly air dry. The very high values found for the internal forces of air-dry seeds gives us a satisfactory explanation of this power of seeds to absorb large amounts of moisture from relatively dry soils, and of their ability to secure enough water for germination under such conditions.

While the seed, by virtue of its powerful internal forces, can secure water for germination, those forces are fully satisfied and disappear with saturation. As soon as the young seedling begins to establish itself it is left wholly dependent on other much weaker forces for securing its water supply. The seed is admirably adapted to bring about conditions under which these new forces become effective in the life of the plant.